White Paper Report

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Project Director: Lois Price (lprice@winterthur.org)

Institution: Winterthur Museum

Reporting Period: 10/1/2012-9/30/2015

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Putting Theory into Practice:
Sustaining Collections and Saving Energy at Winterthur Museum, Garden & Library

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&

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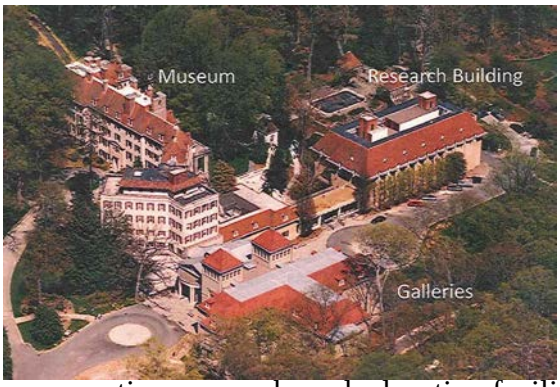
Introduction

Winterthur Museum, Garden & Library is located in the rolling hills of the Brandywine Valley just north of Wilmington, DE. Originally the family home of Henry Francis du Pont, a renowned collector of American art and decorative arts, Winterthur opened as a public institution in 1951. Du Pont's diverse collections are at the center of object-oriented humanities research for over a half century. They are enjoyed by the public, studied by students and visiting scholars, and closely examined by conservators and research scientists in our labs. The 1,000-acre campus includes 118 structures, ten miles of paved roads, a dedicated water and sewer system, and extensive collections that require a specialized preservation environment. These needs create complex control and sustainability challenges for Winterthur's Facilities and Conservation Departments.

The focus of this project, awarded in 2012, was the installation of a new HVAC control and environmental monitoring system that will effectively manage energy and the preservation environment in Winterthur's three major museum and research buildings that house collections of fine and decorative arts, exhibitions, public programs and special events, a library with rare books and manuscripts, conservation and scientific research facilities, and two graduate programs that train cultural heritage professionals. Winterthur's extraordinary resources—its museum, library, conservation laboratories, and science facilities—housed in the museum and research buildings uniquely complement and support one another. Winterthur's curatorial, conservation, and education staff is actively engaged in research and publication. Preservation of the collection is critical to these core activities, and provision of good environmental control is the single most important element in the preservation program. A $350,000 grant from the National Endowment for the Humanities (NEH) program for Sustaining Cultural Heritage Collections funded a significant part of the control upgrades, continuous monitoring, and system refinement that ultimately would develop protocols and procedures useful for other cultural institutions. The success of the grant application was the result of open and intensive collaboration between Winterthur's Facilities and Conservation Departments, and Limbach, Inc., a specialty contractor and maintenance firm, coupled with input from consultants James Reilly of Image Permanence Institute and Peter Herzog of Herzog/Wheeler & Associates.



The core museum complex consists of three interconnected buildings constructed at different times primarily during the 20th century- the *Galleries Building* (35,000 square feet of display space); the *Museum Building* (with 175 rooms furnished with approximately 90,000 objects, works of fine art, and architecture features), and the *Research Building* (housing the Winterthur Library of printed books and manuscripts, and extensive conservation, research, and education facilities). Collections of diverse materials like these require a stable environment that controls temperature and relative humidity within fairly narrow parameters. The complex physical plant and inadequate monitoring and control systems challenged the system's ability to provide adequate environmental control. Massive

amounts of energy were required, straining the institutional budget and gave Winterthur a significant carbon footprint. Winterthur's facilities staff working with conservators had undertaken several efforts during the last decade to develop energy-saving protocols but was consistently frustrated by the inability of monitoring systems to provide reliable, real-time environmental information that would ensure collection safety while conserving energy. In this project, a unique team of engineers, facility and energy managers, collection conservators and preservation environment consultants united toward a common goal. Ultimately, they created a solution that resulted in a 30% energy reduction and improved the preservation environment. The project has also tested a new control/monitoring interface created by the Image Permanence Institute, developed a methodology for energy saving operational protocols that will benefit other institutions, and allowed Winterthur to divert funds from reduced energy costs to other activities that support its humanities-based mission.

Project History and Design

Within the last decade Winterthur moved from attempting to maintain conditions at 70°F ± 2° and 50% RH ± 3% to more flexible set points reflecting current research with winter ranges of 68°F ± 3°, 40% ± 5% RH and summer ranges of 73°F ± 3° and 50% ±5% RH. These standards were set after reviewing recent research that revealed that, while objects react fairly rapidly to temperature changes, they take extended periods of time to react to changes in RH and can safely tolerate much broader environmental changes, particularly when these changes are gradual and within a moderate range.

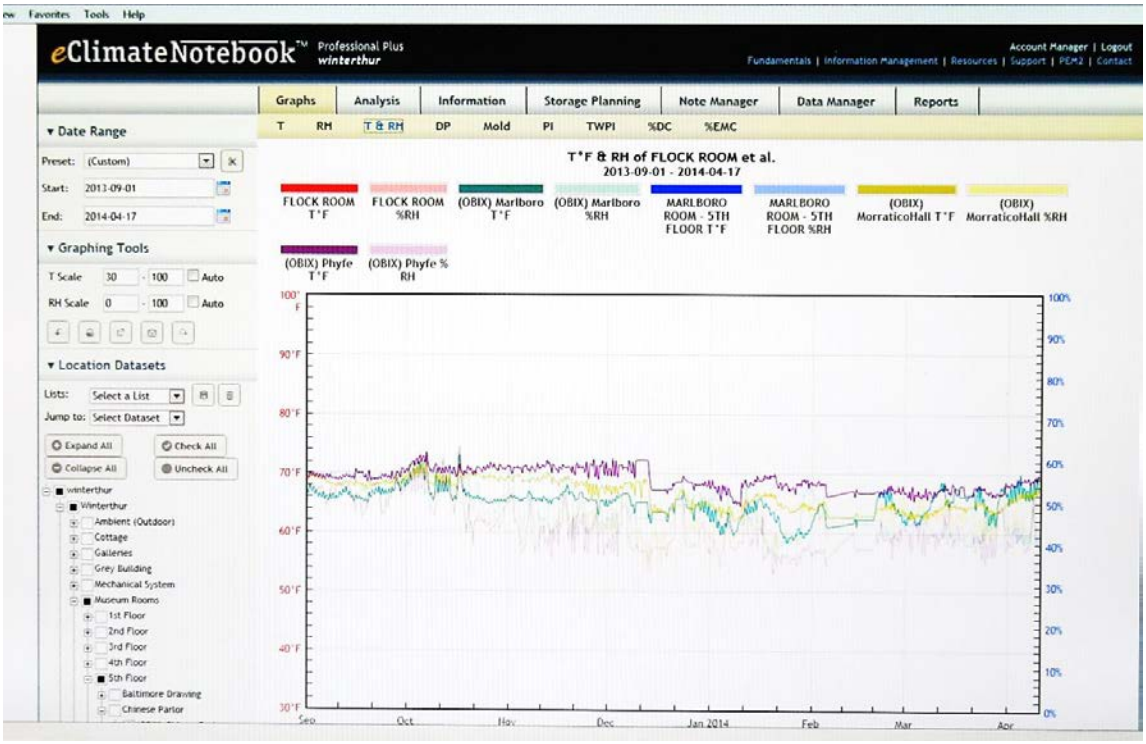
Because of the obsolete monitoring and control system and the challenges posed by Winterthur's complex physical plant, implementing this more flexible approach was difficult and only marginally successful. Winterthur's three major collection buildings were constructed at a different time and each has unique problems, but all three were linked to the same obsolete, inadequate control systems. The HVAC system controls and equipment installed over the years were sized and designed to maintain an environment set to a very narrow range-- 70°F ± 2° and 50% RH ± 3% year round -- a "set it and forget it" system. Attempts by Facilities staff with limited resources to make energy-saving operational adjustments that allow significantly broader daily and seasonal ranges for temperature and relative humidity were complicated, time-consuming and sometime impossible.

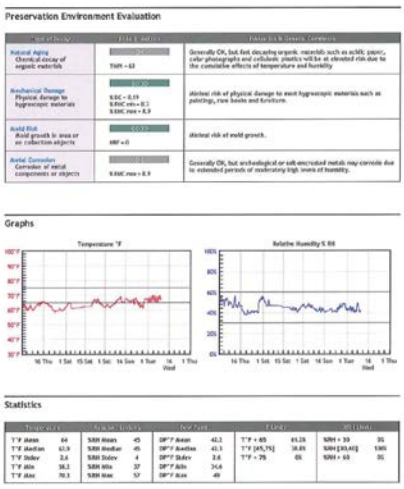
The mechanical infrastructure for these buildings includes a central steam plant with three boilers, two central chilled water plants, multiple high and low pressure air handlers, hundreds of induction units, multiple fan coils and many pumps. These systems are tied together through a network of false walls, pipe chases, tunnels and hidden mechanical alcoves previously controlled by three obsolete pneumatic control systems that could not communicate with each other. This complex system evolved over many decades through undocumented changes and adjustments that were frequently counterproductive.

In early 2012, Director of Facilities John Castle contracted with Limbach, Inc.'s office in Warrington, PA, to initiate a comprehensive audit of the HVAC system; Limbach already provided back-end maintenance services for the systems and was familiar with existing issues. In May, Castle shared the detailed report with Lois Olcottt Price, Director of Conservation, who also advocated for a more stable and sustainable collection environment.

The recommended mechanical upgrades were fairly straightforward, ranging from boiler burner and air-handler control upgrades to variable-frequency-drive installation. The monitoring and system control issues, however, required radically new thinking. Winterthur had undertaken several efforts over the last decade to develop energy-saving protocols, but was consistently frustrated by the inability of monitoring systems to provide reliable real-time environmental information that insured collection safety while conserving energy. Limbach's pivotal recommendation, therefore, was installation of a unified, web-based system that monitored and controlled the entire mechanical system—every fan, valve, motor, damper, air handler, boiler, and chiller—allowing for accurate, real-time observation and adjustment from anywhere in the world (with internet access).

Although reasonably confident in Limbach's findings and recommendations, Winterthur enlisted James Reilly of the Rochester, New York-based Image Permanence Institute (IPI) and Peter Herzog of Herzog/Wheeler & Associates (St. Paul, Minn.) to review the proposal and meet with Limbach, and Winterthur Facilities and Conservation staff. Reilly, often partnering with Herzog, has become the leading consultant for cultural heritage institutions working on energy/sustainability projects. IPI's research has led to a much better understanding of the environmental needs and tolerances of collection materials, and explored the ability of structures (under favorable weather conditions) to buffer the environment without the intervention of HVAC systems. They also developed tools, such as eClimateNotebook, that help quantify the response of objects to different conditions and balance that with reduced energy consumption that does not compromise collection preservation. Reilly and Herzog raised useful questions and made a game-changing suggestion: create an interface that would automatically populate eClimateNotebook with data gathered by the web-based control system.





eClimateNotebook is a web-based system developed for cultural heritage institutions that incorporates ease of use, powerful data analysis, and extensive data management features that allow collection and facility managers to assess the response of objects to different environmental conditions. The program assesses the risk of natural aging (oxidation), corrosion, mold, and mechanical damage (caused by large fluctuations in relative humidity). An analytic tool incorporated into the program predicts the risk associated with various combinations of temperature, relative humidity and dew point to inform cost-benefit decisions. Data has traditionally been entered into eClimateNotebook from data-loggers downloaded at regular intervals, but an interface would allow collection managers to see real-time conditions in collection areas and immediately assess risks and benefits from changes in control settings.

Project Activities

During the project, Winterthur implemented 33 facilities improvement measures (FIM). These FIM's improved the environment, upgraded infrastructure, reduced energy consumption, instituted effective real-time system monitoring and gave both facilities staff and conservators the tools to track and understand what is happening in the mechanical system and in collection spaces.

While these upgrades are critical, the most significant change has been in the assumptions that govern control of the HVAC system. For many decades, cultural institutions demanded flat line energy control at 70°F and 50% RH with very tight tolerances. Winterthur's system was designed and run to meet those standards, meaning that all components – chillers, air handlers, and boilers – functioned at near 100% capacity much of the time and controls were set to the worst case scenario and then left. For example, reheats were set at 82°F winter and summer, requiring induction units that adjust the air temperature in each room to overcome a large temperature differential to cool the spaces in the summer. Reheats are now programmed to coordinate with both the supply air and outside temperature, providing more nuanced control and significant energy savings.

The project was designed in two phases. The primary activity during Phase I funded by Winterthur was investigation, documentation, mapping and upgrading of mechanical control systems and installation of the Tridium wireless control and monitoring system. Phase II, partially funded by the NEH grant, continued the investigation, upgrade and repair of controls, developed the eClimateNotebook interface, and initiated a web-based monitoring program coordinated with energy-saving system adjustments. Many mechanical upgrades accomplished in Phase I were necessary to allow the desired degree of control as well as improve efficiency. For instance, replacing boiler burner controls to allow a 1:10 turn down ratio and installing a variable frequency drive, allowed the boiler output and energy consumption to be much better coordinated with the real needs of the system and outside

conditions on any given day. Winterthur went from using two boilers in the winter to one on most days.

The major project components of each phase include:

Phase I

- Installation of Tridium, a unified web-based Building Automation System (BAS) based on the open-source Niagara Framework. The Niagara Framework is a software platform used to manage and control diverse systems and devices — regardless of manufacturer or protocol, meaning Winterthur can change systems and vendors in the future.
- Mechanical upgrades to air handlers, boilers and chillers including controls and sensor upgrades that report to the Tridium system in real-time.
- Analysis, documentation and mapping of the air handler system configurations in all three buildings

Phase II –

- Installation of both wired and wireless sensors throughout all three buildings that report real-time conditions to the Tridium web-based system using the new Building Automation System. Sensor density went from an average of three per floor in the Museum to eight and from one per floor in the Research Building to one per room.
- Construction of an interface between Tridium and the eClimateNotebook data analysis system to share real-time data. This allows collection staff to use eClimateNotebook's powerful analytics to understand and trend the collection environment and communicate effectively with Limbach and facilities staff.
- Using the new web-based system, Winterthur staff tested new energy saving operational protocols using data from the Tridium/eClimateNotebook control system to carefully monitor collection areas. These protocols include shutting down environmental control systems or changing settings during periods of moderate weather, particularly at night, when the natural buffering capacity of the buildings can maintain acceptable conditions. The Collection Sustainability Committee composed of Winterthur facilities and collection staff, with consultation from IPI/Herzog, reviewed the monitoring data and operational protocols as they were developed and tested to insure the changes met the goal of reducing energy consumption without compromising the preservation environment.
- Upgrades of mechanical and control systems that improved efficiency and reduced energy consumption:
    - Installation of variable frequency drives on Galleries air handlers and a boiler draft inducer fan for the Museum to allow better airflow and reduce energy consumption
    - Installation of "soft starts" on all air handlers to prevent excess belt wear with more frequent, often daily, restarts.
    - Repair and proper control of variable air volume units in the Galleries which significantly stabilized relative humidity conditions

- Installation and programming of controls for the Conservation ventilation system in the Research Building
- Restoration of return air in two Museum air handlers
- Installation or plans for installation of reheat, humidification and/or dehumidification capacity in un-served areas
- Replacement of small, aging local air handlers
- Survey (400 units) and repair of all Museum induction units

Accomplishments and Challenges

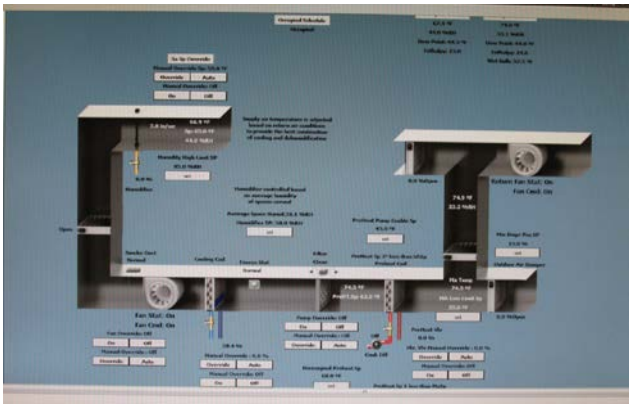
This project has successfully met its proposed goals. A new HVAC web-based control system, accompanied by significant mechanical upgrades, has improved the overall collection environment and decreased energy consumption by 30% in the three collection buildings – 10% more than predicted. From 2012 to 2014, the number of degree-days (a measure of heating/cooling needs based on a complex formula) rose from about 5,050 to about 5,750. However, Winterthur's gas consumption in the three collection buildings fell from 460,130 cubic feet in 2012 to 217,070 in 2015. Electric use fell from 8,837,391kilowatt hours in 2012 to 6,824,238 in 2015, bringing the annual cost of energy supply to collection buildings (electricity and natural gas) from $1,349,256 annually in 2012 at the beginning of the project to $691,493 in 2015. (Figures for 2015 are projected since data for December was not available.) While part of this 50% cost reduction is due to decreases in energy cost, approximately 30% of this saving is from a reduction in energy use. Access to real-time data and web-based control allows facilities staff to respond more efficiently and effectively to system malfunctions. They can now see how every blower, damper, valve, chiller, motor and reheat is functioning and adjust settings remotely.

The vastly improved collection environmental monitoring capacity and the ability to see trends in eClimateNotebook have revealed many anomalies and problem areas that have been systematically investigated. Each seasonal change reveals new issues, but the causes are sometimes difficult to identify once mechanical and control issues have been eliminated. Causes have ranged from the intrusion of outside air entering through undocumented, stand-alone exhaust fans and dampers or uncapped chimneys to heat ducts that ascend adjacent to chimney flues. These issues have probably been there for years, but we could not identify them in the existing system, and collections have probably suffered. The most problematic areas are those that were not designed for collections but which have been repurposed for storage over the years. Some were retrofitted for better climate control and some were not. Retrofits included inadequate add-ons to the existing system that now need to be redesigned and replaced with more effective and efficient options. Some areas need the addition of reheats, humidification or dehumidification.

The project documented known problems, but revealed many more surprises—some of them serious—than anticipated. As the project has progressed, the list of anomalies and problem areas has gone from a couple pages to less than half a page, and for most of these, the cause

has been identified. Dealing with these problems has created budget issues, but the energy and cost savings, as well as the reductions in equipment wear and depreciation, will largely offset these costs over the next several years. Payback dates have not been calculated because of variable energy costs.

With monitoring and control systems installed and functional and eClimateNotebook arranged and mapped for easy access, Winterthur began developing, testing, and documenting energy saving operational protocols. These have included major changes like energy cycling - shutting down air handlers and chillers from 6:00 pm to 6:00 am when outside temperatures and dew points are relatively moderate. Energy cycling began in January 2014 to test the buffering capacity of the Museum (its ability to maintain adequate temperature and relative humidity) if the chiller and air handlers are turned off at night. The team discovered that during winter months, buffering for this building was adequate to 25°F and during summer months up to 80°F. Similar testing, taking outside temperature, RH, and dew point into consideration, was conducted for all seasons and buildings since buffering capacity varies with building construction and materials. More nuanced control will further enhance savings – on cool, dry summer mornings the system may engage later and the chilled water temperature may be allowed to rise a degree (10% energy savings) if the forecast is moderate.



Achieving this degree of control over the system requires continuous and knowledgeable monitoring of hundreds of data points. This has raised new issues and resulted in several discussions between Winterthur and Limbach staff and consultants Jim Reilly and Peter Herzog. Project Director Lois Olcott Price regularly monitors collection conditions using eClimateNotebook and is training Preventive Conservation staff to gradually take over this function as protocols and reporting procedures are established. Winterthur and Limbach staffs respond to the multiple alarms generated by the Tridium system to adjust equipment functioning and make repairs. The ability to monitor and adjust every piece of equipment wirelessly has resulted in faster and far more effective response to problems. But the additional time necessary to make nuanced energy-saving adjustments based on changing outside conditions and develop reproducible guidelines and protocols has not been available.

Winterthur and Limbach, therefore, began a program of continuous commissioning in November 2014. Continuous commissioning is a relatively new concept that places skilled (Limbach) staff in the field on a regular basis to resolve operating problems, improve environmental control, and optimize energy use. As equipment ages and space and mechanical conditions change, the response required by the control system is affected. Therefore, on a regular basis, system and "loop tuning" is required to optimize the response of the control system. This involves monitoring and adjusting the timing of dampers,

control valves and pneumatic transducers to the input signals from humidity and static pressure transmitters and temperature sensors to the present environmental controls. Limbach also carries out field tests to identify any system shortcomings and unnecessary energy usage.

Limbach submits a monthly summary of activities detailing major findings and system adjustments to Winterthur facilities and conservation staff. Conservation staff produces a monthly collection conditions report noting problem areas and questions. Response to both reports is due within two weeks of submission. Winterthur facilities and conservation staff and Limbach meet quarterly to review reports and plan projects. Limabach staff will assess progress and evaluate what monitoring functions can be turned over to Winterthur staff using the parameters that have been developed. Winterthur will ultimately face the choice of continuing to partner with Limbach or hiring a professional level staff member to spend at least part-time doing continuous commissioning. Either scenario is feasible and will be largely paid for by the energy savings achieved.

Lessons Learned:

A project of this size and complexity inevitably generates a list of discoveries, unintended consequences, and unanswered questions. These have posed a variety of challenges and a significant learning curve for all involved. The most significant lessons learned include:

1. An energy audit must be accompanied by an intensive and well-documented mechanical and control system investigation, documentation and mapping to maximize energy saving and prevent systemic inefficiencies. This is an investment that will keep on giving.
2. Minor and often undocumented changes and adjustments to an HVAC system to address immediate problems will often have unintended consequences. Cumulatively, the system becomes less effective and efficient.
3. The fact that a system is maintaining environmental conditions within acceptable parameters most of the time does not mean that it is functioning well or functioning efficiently. Be prepared for unwelcome surprises.
4. Having collection staff work closely with facilities staff and project engineers is essential since each only understands part of the problem and part of the solution. Each must become engaged in thoroughly understanding and applying all the basic information brought to the table.
5. Do not underestimate the need to collaborate with the IT department and allow money in the budget for IT upgrades needed to support the digital control and monitoring systems.
6. Having an outside consultant with a broad perspective like Jim Reilly of IPI review the project and meet with all stakeholders after the bulk of the investigation was completed was very valuable in setting priorities and planning for the protocol development stage.
7. Protocol development for adjusting climate control/energy consumption to coordinate with outside conditions is difficult and complicated by an ever changing outside environment and ongoing changes and repairs to the mechanical system; there are many shifting variables. It may always be a work-in-progress.

8. As Jim Reilly warned at the beginning of the project, "Someone needs to drive the bus. You need to decide who that will be." We now have an extraordinary amount of very useful data, but it takes a skilled HVAC expert who understands the museum environment to interpret it and then implement appropriate actions to maintain the environment and save energy. Part of your energy saving will need to go to maintaining and monitoring a more complex and demanding system.

Impact

When the award was announced, all three Congressmen from the State of Delaware were present at Winterthur, which exemplifies the level of publicity and attention this project has attracted. John Castle was named Energy Manager of the Year in 2015 by the Greater Philadelphia Chapter of the Association of Energy Engineers, and Lois Olcott Price has been asked to publish the project in periodicals such as *Retrofit* and *Papyrus* and present papers at professional conferences such as AIC.

In addition to this welcome publicity and increased visibility, this project has four major long-term impacts for Winterthur Museum, and for other institutions protecting cultural heritage:

1. It has significantly reduced Winterthur's carbon footprint. The BAS system has been extended beyond the three collection buildings to all the major buildings on the property, resulting in a 30% overall reduction in energy use. Given the issues related to climate change, this is an extraordinarily important result.
2. The reduction in energy use has provided important, long-term relief to Winterthur's operating budget, bringing the annual cost of energy for the three collection buildings (electricity and natural gas) from $1,349,256 annually in 2012 at the beginning of the project to $691,493 in 2015. While part of this is due to decreases in energy cost, much of this saving is from a reduction in energy use. Funds that are not spent on energy can be spent on other high priority mission driven activities like exhibits and programing.
3. The real-time monitoring system that provides access to environmental data in every collection area has identified many areas that suffered from poor environmental control. Resolution of the underlying problems has improved environmental conditions significantly, resulting in better long-term preservation of the collections.
4. The eClimateNotebook interface and lessons learned in developing energy saving protocols will be shared with other cultural heritage institutions addressing similar challenges. IPI is already working with other institutions, such as the Shelburne Museum (Shelburne, VT), to integrate the interface into BAS systems.

Information about Winterthur can be found at www.winterthur.org
Information about Limbach, Inc.: www.limbachinc.com
Information about Image Permanence Institute: www.imagepermanenceinstitute.org
Information about Tridium, Inc: www.tridium.com